Marketing Research Report No. 642

Improved Sulfur Dioxide Fumigation of GRAPES Loaded in Railway Refrigerator Cars

U.S. Department of Agriculture
Agricultural Marketing Service
Market Quality Research Division

PREFACE

This report describes an important phase of the Department's research program on reducing post-harvest decay losses and maintaining quality in fresh table grapes. Effective fumigation of grapes in railroad refrigerator cars is necessary to prevent spoilage in transit and during marketing, and also to prevent injury to the fruit.

Related reports on grape storage and shipping include:

The Cold Storage of Vinifera Table Grapes. U.S. Dept. Agr. Handbook 159, June 1959.

Instructions for Forecasting Decay in Table Grapes for Storage. U.S. Dept. Agr. AMS-392, August 1960.

Market Diseases of Grapes and Other Small Fruits. U.S. Dept. Agr. Handbook No. 189, November 1960.

Protection of Rail Shipments of Fruits and Vegetables. U.S. Dept. Agr. Handbook No. 195, July 1961.

A copy of any of these reports may be obtained by writing to the Marketing Information Division, Agricultural Marketing Service, U.S. Department of Agriculture, Washington, D.C., 20250.

The assistance and cooperation of the following firms and their representatives are acknowledged:

Bianco Packing Co., Inc., Sanger, Calif.; Central Empire Storage, Fresno, Calif.; DiGiorgio Fruit Corporation, San Francisco, Calif.; Elmco Cold Storage, Porterville, Calif.; L. R. Hamilton, Inc., Reedley, Calif.; Mt. Whitney Storage, Exeter, Calif.; Morris Fruit Co., Fresno, Calif.; Snowden Enterprises, Inc., Modesto, Calif.; Pacific Fruit Express, San Francisco, Calif.; and Santa Fe Refrigerator Dept., Los Angeles, Calif.

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PRECAUTIONS TO FOLLOW WHEN USING SULFUR DIOXIDE

Human Toxicity.--The pungent odor of sulfur dioxide is easily recognized and can be detected in concentrations as low as 30 to 40 parts per million (p.p.m.). At 400 p.p.m. the gas becomes extremely irritating and can cause injury to the mucous membranes of the eyes, nose, and mouth. At 2,500 p.p.m. (0.25 percent, the concentration commonly used to fumigate grapes in storage), the gas can cause respiratory spasms and death if the victim cannot escape from the fumes.

If exposed to irritating concentrations of the gas, affected areas should be flushed with large quantities of water. A few drops of dilute ephedrinal sulfate will give relief when applied to the nose. Goggles and a gas mask effective against acid-type gases should be worn in the presence of even weak concentrations of the gas.

Injury to Other Commodities.--Grapes are almost unique in their ability to withstand sulfur dioxide fumigation. Concentrations of the gas commonly applied to grapes cause severe injury to almost all other fresh fruits and vegetables. If grapes are shipped in mixed loads with other fruit in a refrigerator car, the car must not be fumigated. Severe injury to peaches, nectarines, plums, and other commodities has been observed when these fruits have been shipped with grapes in fumigated cars.

Corrosive Effect on Equipment.--Sulfur dioxide forms sulfurous acid when dissolved in water. Metal surfaces upon which moisture collects become covered with sulfurous acid during and after fumigation. The acid is extremely corrosive to both iron and zinc, causing the deterioration of coils and other equipment made of these metals. Some protection is afforded by treating exposed metals with acid resistant paints. A minimum of electrical wiring should be exposed to the gas and switches and other control equipment should be located outside the area being fumigated if possible.

Other Precautions.--Grapes treated with bisulfite should not be refumigated with sulfur dioxide, because bleaching may result from the combined treatment.

IMPROVED SULFUR DIOXIDE FUMIGATION OF GRAPES LOADED IN RAILWAY REFRIGERATOR CARS

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SUMMARY AND CONCLUSIONS

All California and Arizona table grapes are fumigated with sulfur dioxide before shipment, to prevent decay. Improved methods of circulating the air in refrigerator cars to disperse the gas quickly and uniformly through the load are given in this report. If dispersal is slow or uneven, as is common in commercial practice, underexposure or overexposure results. Underexposure would allow decay to develop, and high concentrations of gas can severely damage the grapes.

Different combinations of fans in the cars were tested with various load patterns and shipping containers. Prepackaged grapes in master cartons cannot be fumigated satisfactorily after loading in the cars.

In standard ice bunker cars, a portable fan was placed in the center of the car between the braces that hold the divided load in position. This fan blew air upward during fumigation and gave uniform gas distribution through loads of grapes packed in 28-pound lug boxes.

Bunker fans also mixed and distributed the fumigant satisfactorily when the gas was applied slowly. High ice meltage absorbed a significant amount of sulfur dioxide and removed it from the car as the water drained out. An additional amount of sulfur dioxide had to be provided to compensate for this loss.

The best results in mechanical refrigerator cars were obtained when the gas was released in the space above the load at the end of the car opposite the blower.

Ice Tempco[2] cars have thermostatic temperature controls, bunker fans, and fans that bypass the ice bunkers to circulate only the air in and around the load. The bypass fans alone did not disperse the sulfur dioxide uniformly in the load. Operation of both the bunker and bypass fans was necessary for satisfactory distribution of the gas.

INTRODUCTION

Fresh grape shipments to eastern markets from California amounted to almost 23,000 carloads in the 1960-61 season and 19,500 carloads in the 1961-62 season. Most of these grapes were fumigated with sulfur dioxide (SO_2) in the refrigerator cars. Grapes that are not stored and are shipped directly to market after harvest, usually receive

[1] Both stationed at 2021 South Peach Ave., Fresno, Calif.

[2] Use of the name "Ice Tempco" is for identification only, and does not constitute special approval or disapproval of this car in comparison with others of similar design.

only the one fumigation in the car. Grapes that are stored usually receive several fumigations before shipment, but in most cases are gassed again in the car.

Sulfur dioxide effectively controls decay of grapes but excessive amounts of gas damage plant tissues and injure the fruit.[3] Injury is manifested as a bleaching and pitting of the berry surface and usually is accompanied by a bleaching and sinking of the tissue around the capstem. Although such injuries can result from fumigation in storage rooms or in railway cars, grapes stacked near the center doorway of railway cars, where gas concentrations appeared to be particularly high, were sometimes severely injured.

Some shippers introduce sulfur dioxide into the car with no facilities for mixing and distributing the gas. Either 3 or 5 pounds of sulfur dioxide is usually forced through a tube inserted at the top of the closed door of the car. The cylinder containing the SO_2 is heated to hasten the release of the gas into the car, but the distribution is not uniform within the load.[4] Under such conditions, fruit at some positions in the load may be exposed to damaging concentrations, while fruit at other positions may not be fumigated sufficiently to control decay. Little was known of gas concentrations at different locations in the car and how these concentrations changed during fumigation.

These tests were conducted to determine gas distribution patterns in various types of refrigerator cars, to determine changes in concentration of SO_2 at various positions in the load as a function of time, and to develop methods of improving the dispersion of the gas in loaded cars.

EXPERIMENTAL PROCEDURES

Gas sampling tubes were placed in the centers of packed grape lugs and in adjacent air channels between lugs during the loading of the car. Figure 1 indicates the positions in the car from which gas sample streams were drawn for analysis. Any exceptions to this sampling scheme are indicated in the results for a particular test. The Emperor variety of grape was used in most of these tests and, with few exceptions, each car was fumigated with either 3 or 5 pounds of SO_2. Usually the gas was released from an SO_2 cylinder preheated in hot water and was passed into the car through a tube inserted at the top of the doorway. The full charge of gas was released in 5 to 10 minutes.

After the fumigation, the gas was usually removed from the cars by starting the bunker fans, which caused the SO_2 to be absorbed in the water melting from the ice.

During the tests, the gas sample streams were drawn simultaneously and continuously from each position at a rate of 400 ml./min., using a peristaltic-type pump with multiple lines (fig. 2). A manifold allowed samples from each line to be analyzed intermittently for SO_2 by passing the sample through a positive nondispersion-type infrared analyzer.[5] Analyses of samples from each line were continued until relatively constant readings were obtained. Drawing samples continuously did not materially change the concentration within the lug boxes (table 1).

The concentration of the gas taken from each position was determined at approximately 2- to 4-minute intervals, depending upon the number of lines from which samples were being drawn. The calibration of the analyzer was checked before and after each test, by passing a sample of a known concentration of sulfur dioxide through the analyzer.

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[3] Jacob, H. E. The use of sulfur dioxide in shipping grapes. Calif. Agr. Expt. Sta. Bul. 471. 24 pp. 1929.

Ryall, A. L. and Harvey, J. M. The cold storage of Vinifera table grapes. U.S. Dept. of Agr. Handb. No. 159. 46 pp., illus. 1959.

Winkler, A. J. and Jacob, H. E. The utilization of sulfur dioxide in the marketing of grapes. Hilgardia 1: 107-131. 1925.

[4] Pentzer, W. T., Bratley, C. O., and Tufts, W. G. Report of sulfur dioxide injury in commercial shipments of Tokay grapes, 1942 season. U.S. Agr. Mktg. Serv. 11 pp., illus. (Processed) 1942.

[5] Liston, M. D., Andreatch, A. J., and Beebe, C. Improving the infrared gas analyzer. ISA Jour. 4: 118-123. 1957.

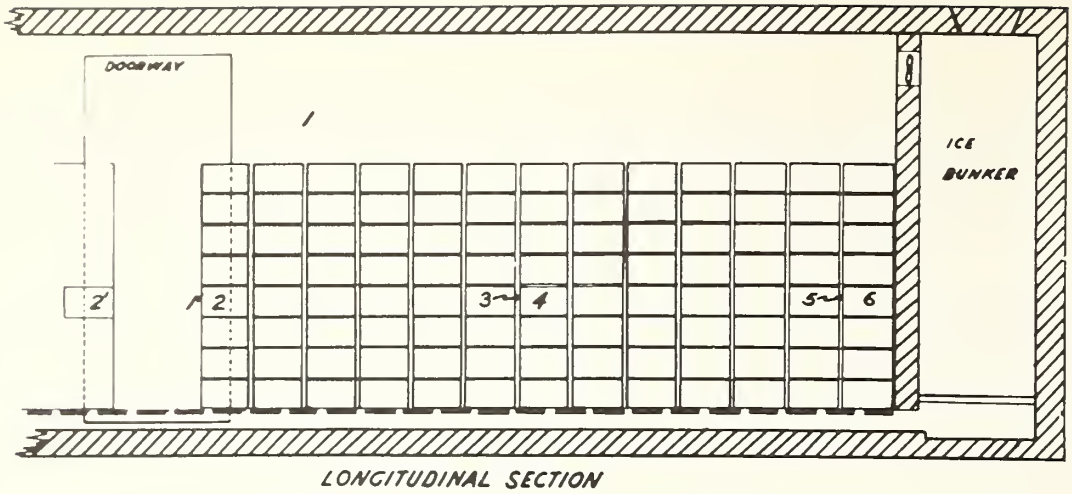

Figure 1.--Positions in refrigerator car from which most of the gas samples were drawn, all in centerline of car.

1 -- Space above load.
1^1 -- Doorway brace.
2 -- Doorway middle, center of box.
2^1 -- Doorway middle, wrapped cluster in center of box.
3 -- Quarterlength middle, air channel.
4 -- Quarterlength middle, center of box.
5 -- Bunker middle, air channel.
6 -- Bunker middle, center of box.

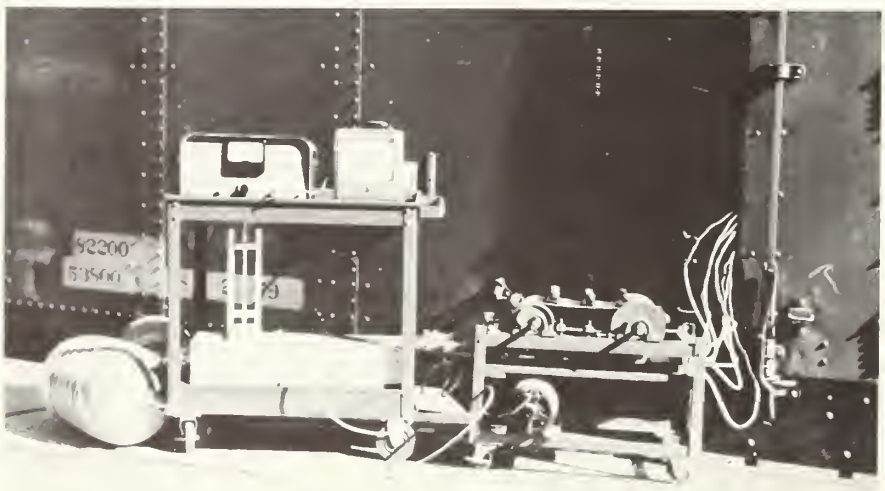

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Figure 2.--Equipment used to analyze SO_2 concentrations in railway cars. The items shown from left to right are: the pressure tank containing gas sample for calibrating the analyzer, the nondispersive infrared analyzer with recorder on a cart, the peristaltic-type pump, and tubes through the door for drawing samples from various positions in the load.

TABLE 1.--Concentration of SO_2 in the center of a lug box of grapes: effect of continuous sampling

Time from release of SO_2	Concentration of SO_2 at indicated position			
	Room air	Center of lug		
		Sampled continuously	Single sample taken at 6 min.	Single sample taken at 12 min.
Min.	Pct.	Pct.	Pct.	Pct.
1	.13	.15	--	--
2	--	--	--	--
3	.15	.15	--	--
4	.15	--	--	--
5	--	.16	--	--
6	--	--	.17	--
7	.20	.18	--	--
8	--	.20	--	--
9	--	--	--	--
10	.20	--	--	--
11	--	.20	--	--
12	--	.17	--	.17

RESULTS

Distribution of Sulfur Dioxide when Applied in the Conventional Manner in Standard Refrigerator Cars

Solid-block load.--In this load, the lug boxes are stacked tightly against one another and blocks are used only to provide a space between the load and the walls of the car. No air channels are left between packages in the load.

When 5 pounds of SO_2 were applied to a solid block load of Emperor grapes the concentration of gas increased rapidly in the air space above the load, but was negligible at positions within the load (fig. 3). A relatively high concentration was found in the box at the periphery of the load, but there was no measurable concentration in the box at the quarterlength position. Only a small amount of gas penetrated the space under the floor racks and a very low concentration occurred under the floor rack adjacent to the bunker.

The concentrations found in the various parts of this load indicated that fumigation with SO_2 under these conditions was of very little value, because much of the fruit was not exposed to effective concentrations of the gas. Fruit in boxes on the periphery was probably exposed to injurious concentrations.

Gate Load.--The stacks of lugs in this type of load are separated from each other by vertical and horizontal wood strips, which provide narrow air channels around each stack of boxes. When this load was fumigated with 5 pounds of SO_2, high concentrations again occurred in the space above the load. Concentrations at the quarterlength and the bunker positions were low even with the vertical air channels (fig. 4). A relatively high concentration of gas occurred in a box containing unwrapped clusters of grapes at the periphery of the load, while a very low concentration occurred in an adjacent box with clusters of grapes wrapped in tissue paper. The fumigant did not diffuse adequately into the air channels between boxes nor into the boxes under these conditions.

During this test the bunker fans were operated for about 1 minute after all of the gas was in the car in an attempt to mix the gas. This procedure caused a sharp decrease of the gas concentration in the space above the load and in the lug box located next to the brace. The decrease was due to dilution of the gas with air in the car and absorption of gas by the water in the bunker.

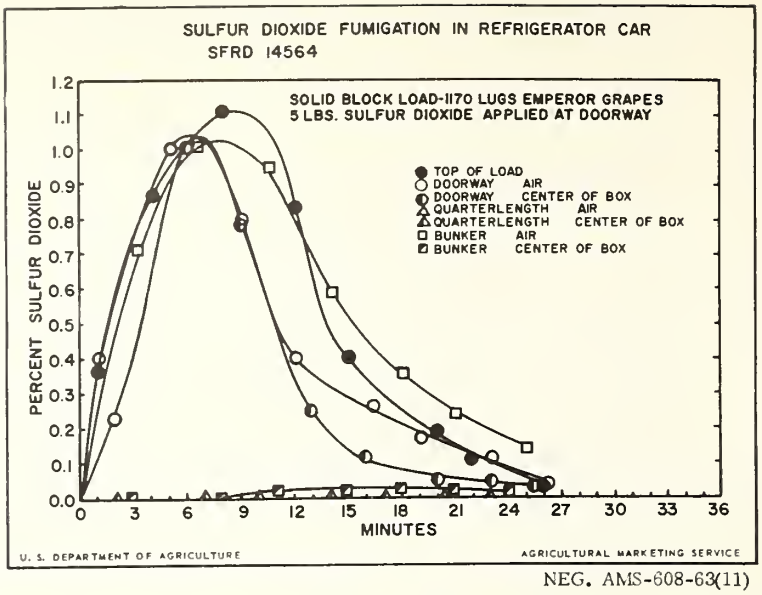

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Figure 3

Some cars are loaded with fruit, fumigated, and left on the track for several hours. During this time the gas is left in the car with little or no mixing, exposing some fruit to damaging dosages of sulfur dioxide. Figure 5 shows gas concentrations in a car fumigated with 5 pounds of SO_2 and left standing for 3 hours. In order to determine the effect of the SO_2 on the fruit under these conditions two test boxes were placed on the top layer of the load during the fumigation.

Sulfur dioxide distribution was similar to that in the previous test. The levels of gas in the space above the load and in a box at the periphery of the load were very high, while that in boxes at the quarterlength and bunker positions was very low.

Two boxes of fruit were removed from the top of the load and examined after 3 days at room temperature. Bleached areas developed around the capstems of the fruit and there was a high percentage of "wet" berries compared to fruit not given this treatment. The foregoing tests showed that fumigation in refrigerator cars can result in severe damage to the fruit, unless the gas is quickly dispersed.

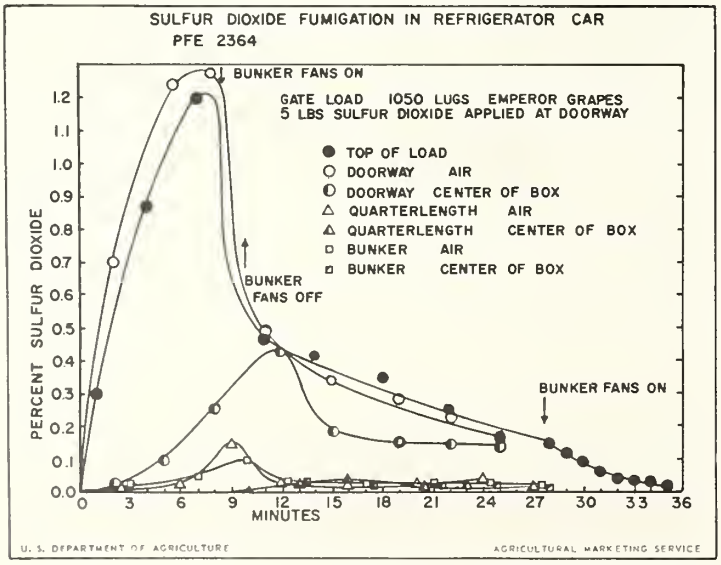

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Figure 4

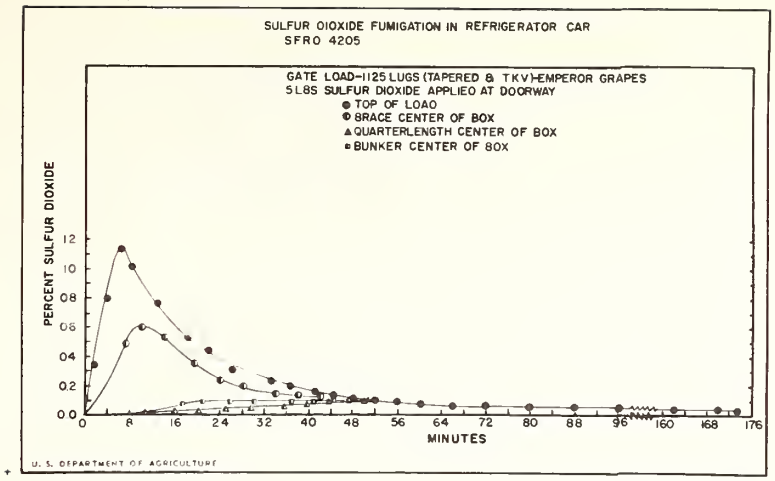

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Figure 5

Spaced-carton load.--This load consisted of 1,062 master cartons, each containing twelve 2-pound consumer packages of grapes. Wooden spacer strips were placed at the corners of each stack to provide very narrow vertical air channels (fig. 6). An extremely poor distribution of SO_2 resulted when this type of load was fumigated with 5 pounds of gas (fig. 7). The sulfur dioxide level in the space above the load increased very sharply after the gas was released in the car, but practically no gas reached the consumer units at any positions from which the samples were drawn. Fumigation of this type of load was of no value.

Figure 6.--Spaced carton load with upright wooden spacer strips at corners of boxes.

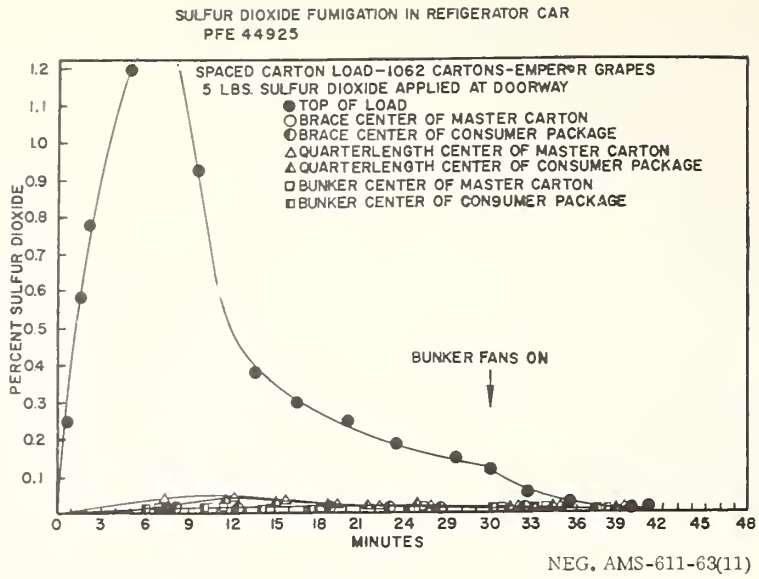

Figure 7

Distribution of Sulfur Dioxide in Standard Refrigerator Cars when a Supplemental Fan was Used in the Brace

The foregoing tests showed that SO_2 was poorly distributed in cars loaded with grapes, when no provision was made for mixing and dispersing the gas. Consequently tests were made to determine the effect of a supplemental fan placed in the brace to facilitate the SO_2 dispersion in the load. This fan was installed 1 or 2 feet above the floor in the brace after the loading was complete. The design of the fan and a baffle permitted easy insertion and removal before and after fumigation (fig. 8).

Gate load with fan in brace directed downward.--The supplemental fan was directed downward and operated continuously during this test, forcing the air under the floor racks and up through the load (fig. 9). The highest concentration measured, 0.6 percent, was in the air above the load and was approximately one-half that in the car with a similar type of load, but without a supplemental fan. Although the fan did reduce the excessively high concentrations at this position, the relatively low concentrations in the boxes at the quarterlength and bunker showed that distribution still was not uniform. There was considerable bypassing or short-circuiting of the air near the fan and a gradual decrease in the air movement away from the brace. Evidence of air movement near the brace was the almost equal concentration of SO_2 in the centers of the boxes with wrapped and unwrapped clusters. In the previous test without a fan, practically no gas diffused into centers of the boxes containing wrapped clusters at these positions.

Gate load with fan in brace directed upward.--Relatively uniform distribution of gas occurred in a car in which the supplemental brace fan was directed upward (fig. 10). The highest concentration in the space above the load was approximately 0.67 percent when 5 pounds of the gas was introduced into the car. The maximum concentrations in the centers of boxes at various positions of the car varied between 0.56 and 0.49 percent, indicating a great improvement in the distribution of the fumigant.

When the gas was forced upward, the space above the load served as a huge mixing and plenum chamber, from which the gas was forced downward through the entire length of the load.

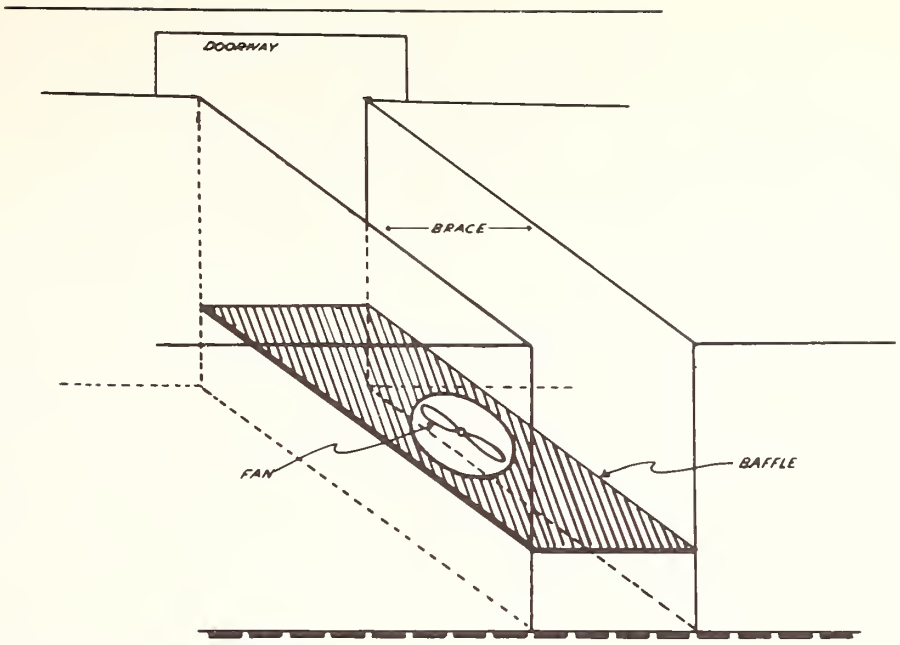

Figure 8.--Schematic diagram of fan and baffle used in brace of grape load in refrigerator car.

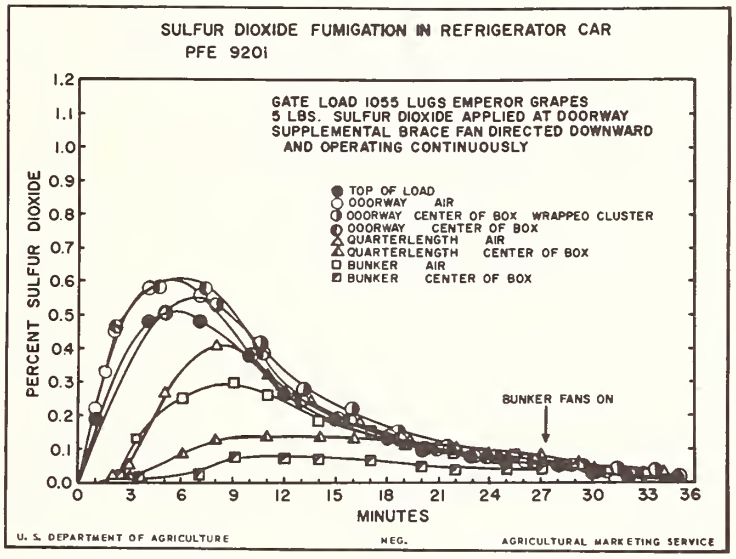

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Figure 9

A similar uniform dispersion of the fumigant resulted when the brace fan was operated and 3 pounds of gas was applied (fig. 11). Although the maximum concentrations of gas were not as high as in a car fumigated with 5 pounds of SO_2, the concentrations at the middle, quarterlength, and end positions did not vary greatly. Because the concentrations were so uniform, the 3-pound fumigation would be sufficient for fruit previously fumigated in storage before loading. The lower concentrations may be helpful in minimizing sulfur dioxide injury to the fruit.

Gate load in an express car with brace fan.--Early-season fruit harvested in the Coachella and Borrego Valleys of California is usually shipped in railway express

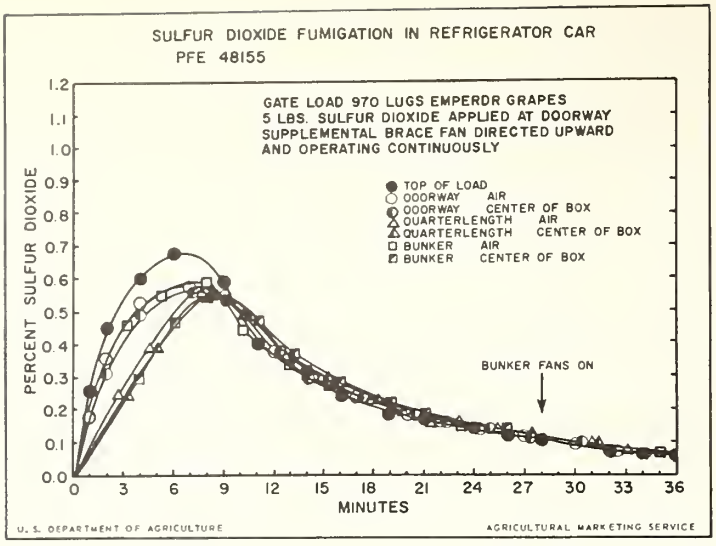

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Figure 10

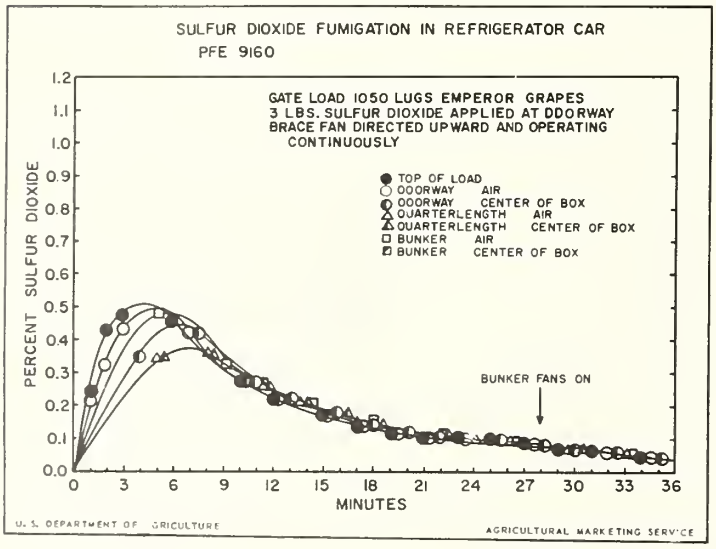

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Figure 11

refrigerator (BR) cars. These cars are about 8 feet longer than general-service (RS) refrigerator cars. An express carload with about the same number of lugs as a load in an RS car would have more stacks, but fewer layers.

A BR express car loaded with 1,035 lugs of Cardinal grapes was fumigated with 3 pounds of sulfur dioxide. Even though a fan was used in the brace, the air tended to short-circuit near it, and little gas reached the boxes in the ends of the car (fig. 12). The distribution of the gas was more uniform in a shorter RS express car with an equivalent number of boxes (fig. 13).

Spaced-carton load with brace fan.--The dispersion of gas in a car containing a spaced-carton load (1,062 cartons with twelve 2-pound consumer units) was not greatly improved with the supplemental brace fan (fig. 14). The gas concentration in a consumer

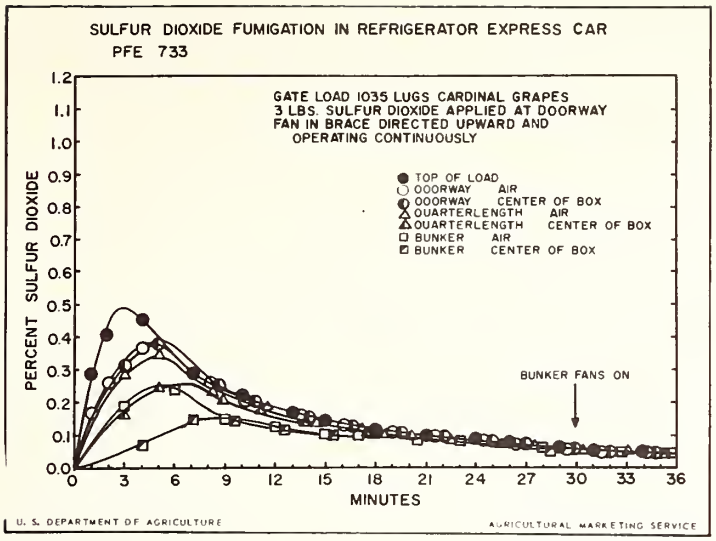

Figure 12

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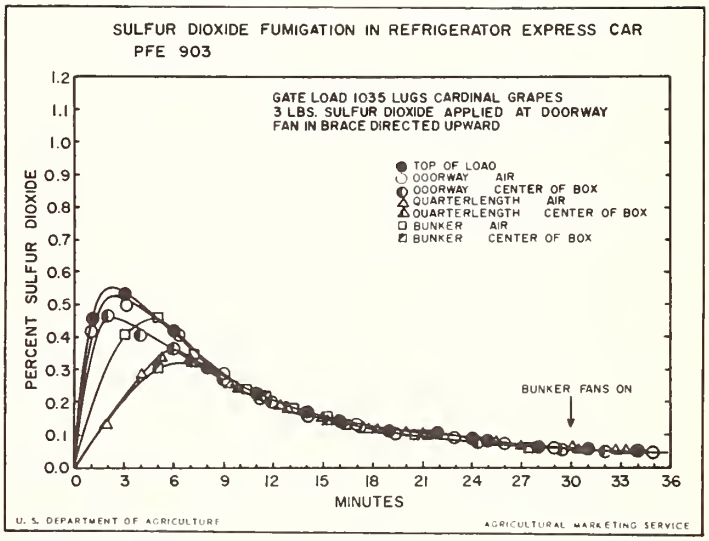

Figure 13

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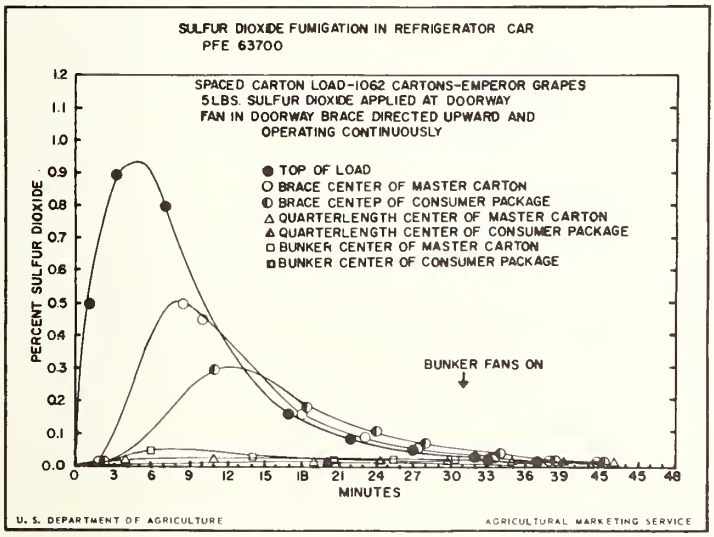

Figure 14

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unit in a carton at the brace position received a maximum of 0.3 percent SO_2, but no measureable amounts were found in either the air channels or the packages at the other positions in the load. Air movement through the load was almost completely restricted as evidenced by the relatively high buildup of sulfur dioxide in the space above the load, even when a brace fan was operating.

Distribution of SO_2 in Standard Refrigerator Cars with Bunker Fans Operating

Many operators are reluctant to use a supplemental brace fan, because of the additional labor required to place and remove the fan, so tests were made to determine the feasibility of running the bunker fans during fumigation. Forcing the fumigant through the bunker ice would result in the removal of some SO_2. Absorption of SO_2, however, would depend upon how fast the ice was melting. In some tests, therefore, salt was added to the ice to increase the meltage. Fruit temperatures in these tests were about 75° F. when loaded. Gate loads consisting of 990 T.K.V. lugs were used. This lug, which has beveled corners, provided larger air channels between containers than in loads of conventional grape lugs.

In this series of tests, the cylinder was not heated until the release valve was opened. Consequently, the gas was released more slowly than with the conventional method in which the cylinder is preheated. The concentration of SO_2 at the doorway and over the load rose rapidly at first and then leveled off before a final rapid release of gas when the heater became effective. This method of application lengthened the exposure of the fruit to an effective concentration of gas and accounts for the uneven rise in SO_2 levels shown in the previous charts.

In the first of four cars, the floor racks at the brace were not covered, allowing unrestricted air passage at this point. In the three remaining cars, the floor racks at the brace were covered with paper to force the air through the load. Figure 15 shows the SO_2 concentration in the first car when 5 pounds of gas was applied and 2 percent salt was added (based on the weight of ice in the bunker). A relatively high concentration was found in the box at the doorway position, but concentrations at the quarterlength and bunker positions were below 0.2 percent except for a brief period at the quarterlength position. The difference in the concentration in the air channel and in the box at the quarterlength indicated that movement through the air channels was relatively slow. Approximately 70 gallons of water melted from the ice during 30 minutes of fumigation.

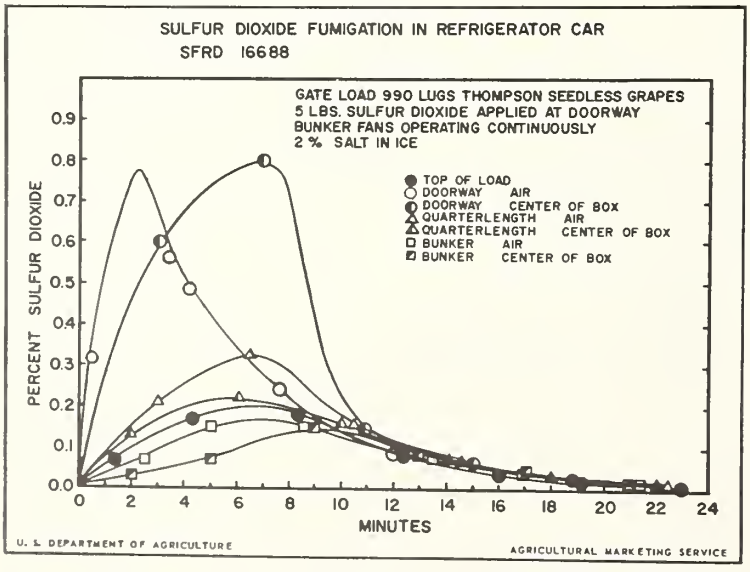

Figure 15 NEG. AMS-618-63(11)

This water absorbed a substantial amount of SO_2 and removed it from the car, as evidenced by the concentration measured in the space above the load. This air had passed through the bunker which reduced the SO_2 concentration about one-fourth.

When the exposed floor racks were covered with paper at the brace, the concentration of the gas in the boxes rose higher and the distribution was more uniform than in the first car (fig. 16). At the box in the doorway, the maximum concentration was over 0.8 percent, while at the quarterlength and bunker positions the maximums were 0.53 and 0.44 percent, respectively.

Water meltage during the 30-minute fumigation was 25 gallons. Although some gas was removed by the melting water, the concentration in the space above the load at the quarterlength rose to 0.65 percent. All of the boxes appeared to have been exposed to an adequate dosage of SO_2 during the test.

Salt (2 percent) was added to the bunkers of another car (fig. 17) to increase the rate of ice meltage. About 85 gallons of water was discharged from the two bunkers in 30

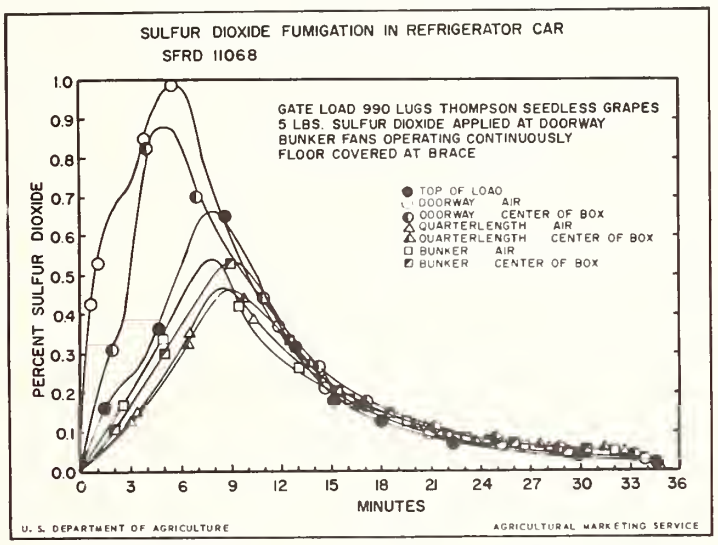

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Figure 16

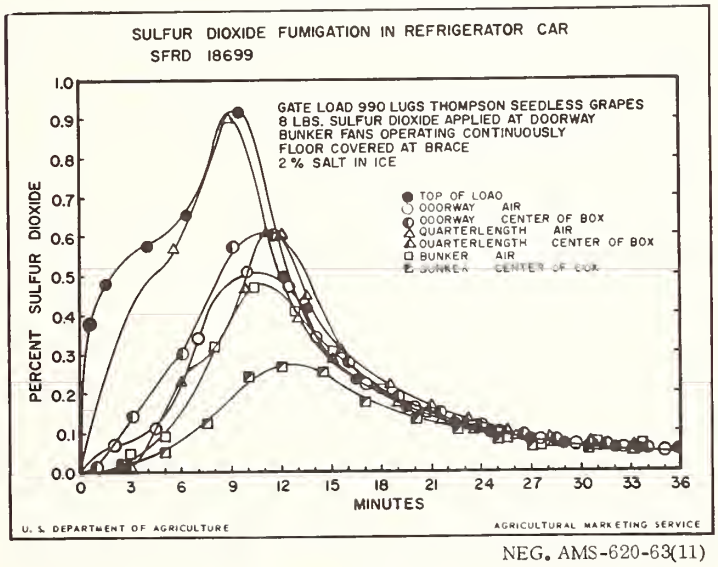

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Figure 17

minutes. Because of the high rate of ice meltage, the maximum concentration of gas in the car rose to only 0.9 percent at the doorway and at the quarterlength position, even though 8 pounds of SO_2 was used. However, the concentration above the load at the quarterlength position rose to only 0.5 percent, which indicated that water removed the SO_2 from the air at a relatively rapid rate. Concentrations in the boxes at the doorway and quarterlength positions rose to 0.6 percent while the maximum level in the box at the bunker was slightly less than 0.3 percent. The levels at all locations appeared to be adequate for satisfactory fumigation of the fruit.

Under the same conditions, but when no salt was added, the concentration above the load reached about 1.0 percent at the doorway position and about 0.7 percent in other locations (fig. 18). Gas distribution was quite uniform and the concentration was adequate.

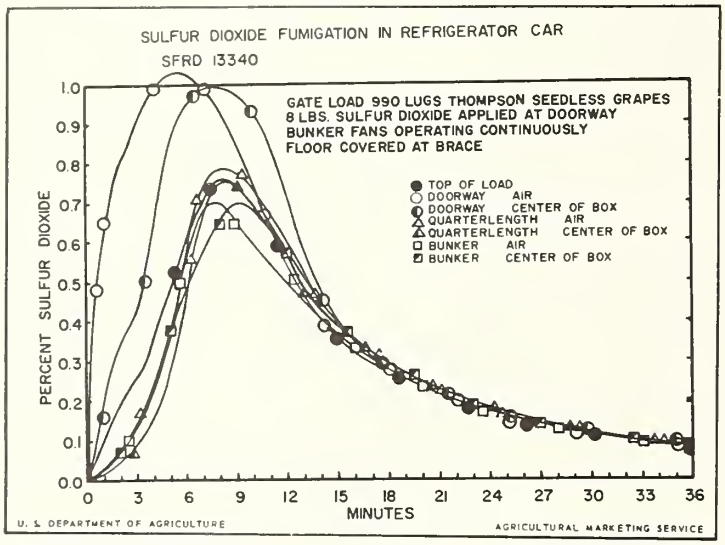

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Figure 18

Distribution of SO_2 in Mechanically Refrigerated Cars

The use of mechanically refrigerated cars for shipping grapes has increased during the last several years. The refrigeration coil and blower are located in one end of this type of car. The air is drawn through the coils and forced into a perforated ceiling plenum chamber from which it is discharged over the length of the load.

Because this type of car is equipped with a blower only in the "A" end, air samples were drawn from both ends of the car to determine variations in the distribution profiles of the gas during fumigation. The doors were opened after the fumigation to exhaust the gas, because there was no ice to absorb the residual sulfur dioxide from the car atmosphere.

Gas released in front of blower in the plenum chamber.--In the first test the gas was released into the plenum in front of the blower. The concentrations at the various positions indicated that the movement of air in the "A" end of the car was much greater than in the "B" end (fig. 19). Although the concentrations of gas in the air channels at all positions were above 0.4 percent, the maximum concentration in the boxes at the quarterlength and end positions in the "B" end were about 0.1 and 0.3 percents, respectively. This indicated that sufficient air movement was present to thoroughly mix the gas, but that the velocity was insufficient to force the gas into the boxes at the end away from the blower.

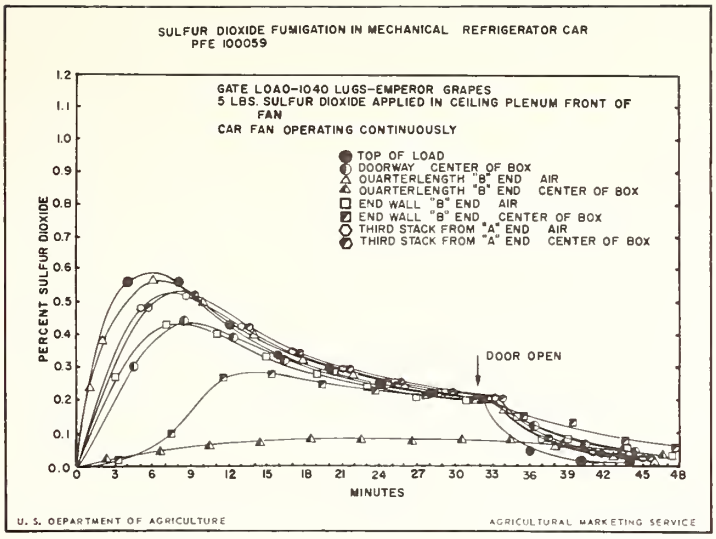

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Figure 19

Gas released in the air space above the load in the "B" end of the car.--Distribution of the gas improved when the gas was released above the load in the end away from the fan or at the doorway (figs. 20 and 21). Although this method did not improve the circulation of the air throughout the load, introduction of the fumigant in the far end of the car provided slightly higher sulfur dioxide concentrations in the air channels and consequently a greater amount of gas diffused into the boxes. Although the concentration in a box at the quarterlength position in the "B" end had the lowest level of gas, the maximum concentration at this position was slightly above 0.2 percent. The box in the end-wall position in the same end of the car had over 0.3 percent gas during the fumigation period.

Gas released under the floor rack at the "B" end of the car.--Figure 22 shows gas concentrations at the various positions when the SO_2 was released under the floor rack at the "B" end of the car. An extremely high concentration of SO_2 was detected in the

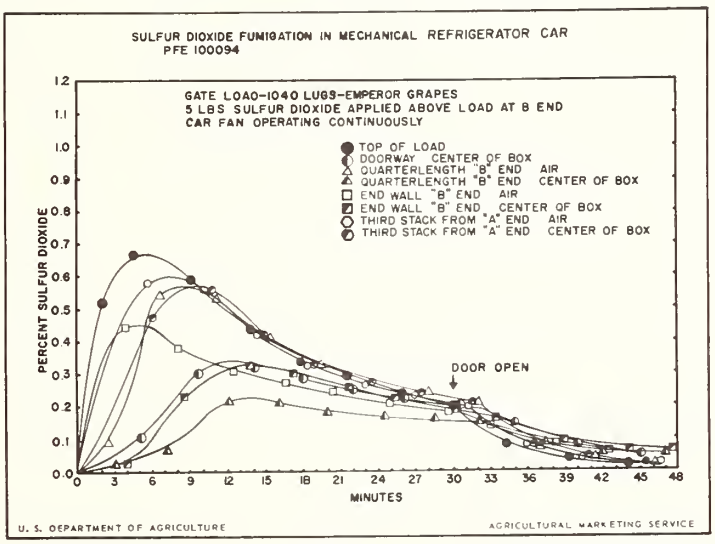

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Figure 20

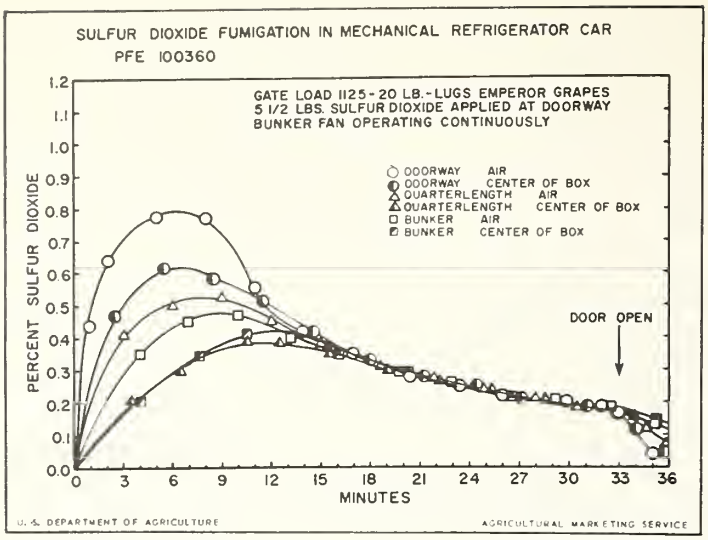

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Figure 21

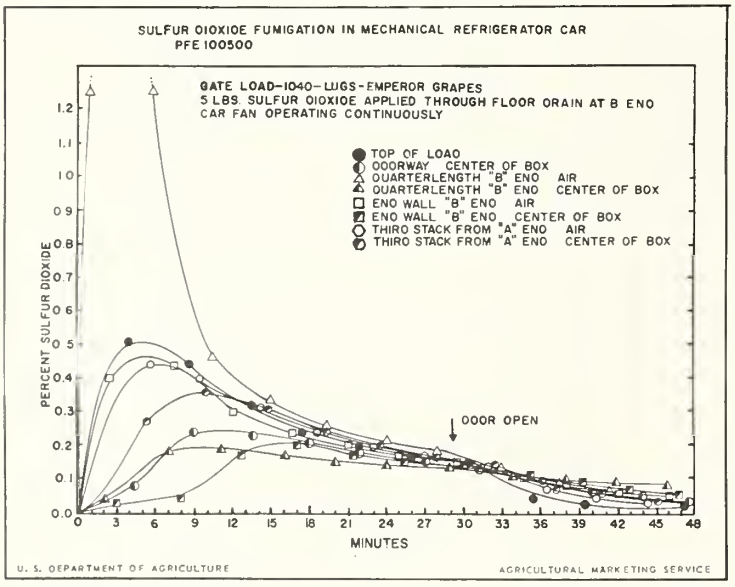

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Figure 22

air channel at the quarterlength position over the point where the gas was released. Except for this position in the "B" end of the car, there was a progressively higher concentration of sulfur dioxide in the samples drawn from the boxes at the positions toward the blower end. The concentration in the box at the quarterlength, however, was lower than that at the end position in the "B" end of the car.

In all four cars tested, the sample drawn from boxes at the quarterlength position in the "B" end had the lowest level of sulfur dioxide. This indicated that the quarterlength area probably had the lowest air movement of the entire car and the air stream was short circuiting through the load in the end near the blower.

Distribution of SO_2 in Ice Refrigerator Cars with Thermostatic Temperature Controls

In recent years, thermostatic temperature control for ice refrigerator cars has been developed. These Ice Tempco cars are modified single-ice-bunker cars, equipped with a small diesel engine to provide power for continuous operation of the fans. A "bypass" fan in each car operates continuously and draws air through a small duct which bypasses the ice bunker and recirculates air within the load compartment. The circulation of refrigerated air through the ice bunkers is controlled by thermostatically activated fans and louvres.

The single bunker of an Ice Tempco car is in the "B" end and has four fans, either one or two of which are used for bypassing the bunker and the remaining two or three for circulating the air through the ice bunkers. Gas samples were drawn from both ends of the car to find how uniformly the gas was distributed.

In the cars tested, one with two bypass fans and three bunker fans (fig. 23) and another with one bypass and three bunker fans (fig. 24), the distribution of SO_2 was extremely poor when only the bypass fans were operating during the fumigation. In both cars very high concentrations of gas accumulated in the space above the load, indicating a lack of sufficient air movement to thoroughly mix the sulfur dioxide with the air. Boxes in the quarterlength and bunker positions in the "A" end of the cars were inadequately fumigated.

To improve air distribution, the Ice Tempco car was modified with a ceiling duct extending from the bunker to the doorway. During a fumigation test in this car, only the two bypass fans were operated. When 6 pounds of sulfur dioxide was used, the space above the load had a very high concentration of gas (fig. 25); the centers of the boxes in the "B" end of the car were thoroughly fumigated, but practically no gas penetrated to the center of the boxes in the "A" end of the cars, even though the gas reached relatively high levels in the adjacent air channels.

Both bunker fans and bypass fans were operated during fumigation of another Ice Tempco car (fig. 26) loaded with fruit precooled to 32° to 33° F. Although the gas concentration above the load was high at first, it was quickly dispersed and samples from all positions became quite uniform. With precooled fruit and low ice meltage, the gas can be drawn through the ice bunker without losing much of it.

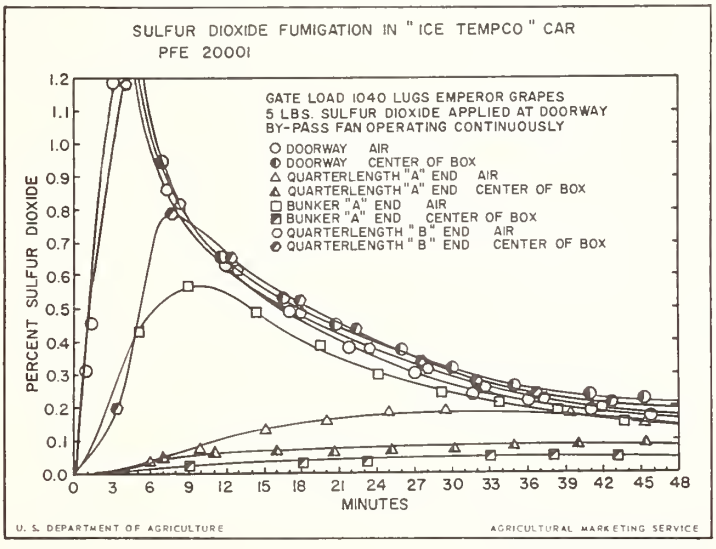

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Figure 23

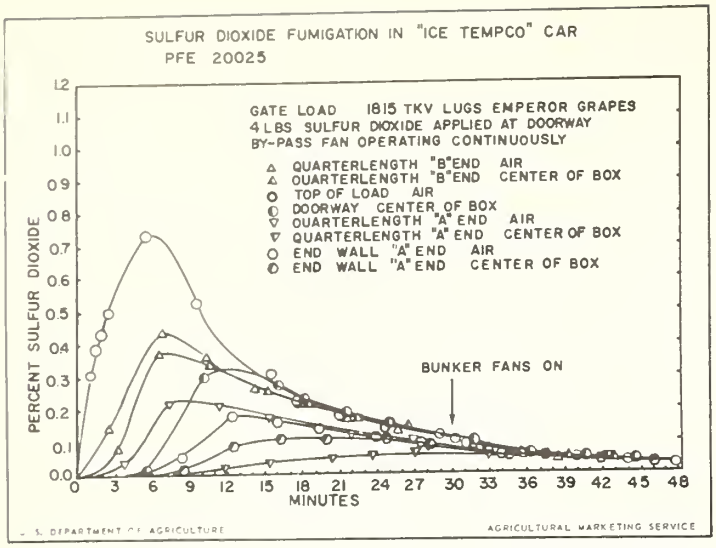

Figure 24

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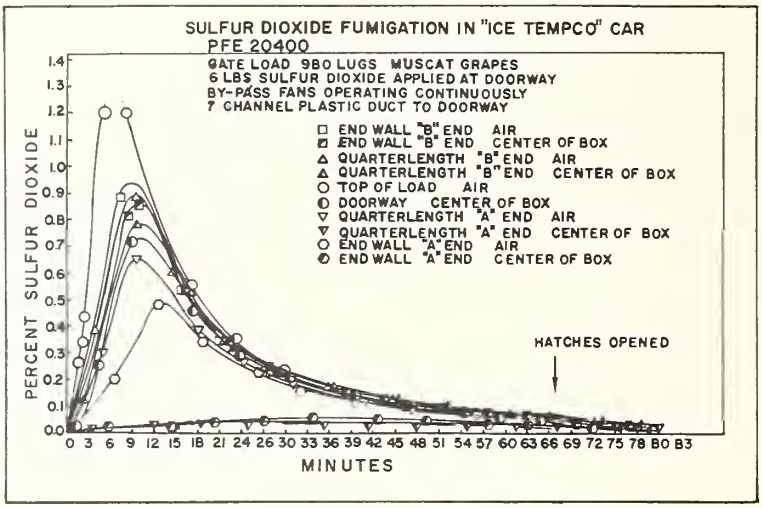

Figure 25

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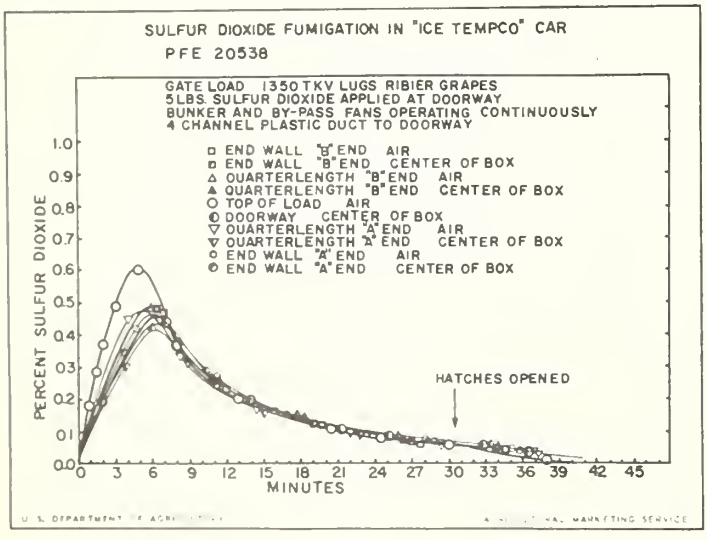

Figure 26

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DISCUSSION

Shippers of fresh grapes customarily exercise extreme care in storing, handling, and fumigating their fruit up to the time they load it into the car. Car fumigation, however, is often performed in a haphazard manner. Very little attention is given either to the distribution of the fumigant or to the exposure time in the car. Consequently the fruit may be either overexposed or underexposed to the fumigant.

Distribution of gas was not uniform in cars fumigated without operation of either auxiliary or car fans. The dispersion of the gas was primarily dependent upon the air circulation in the car. Where thorough circulation was provided, the gas was not only distributed uniformly throughout the load, but also diffused into the boxes. Low air velocity through the channels between the boxes resulted in poor gas penetration into the boxes.

A portable brace fan was the most effective means of distributing the gas through the load and into the boxes. The bunker fans were also effective, but some gas was lost by absorption in the melted ice and additional SO_2 had to be applied to provide a satisfactory dosage of the fumigant. With precooled fruit, the removal of SO_2 was not a significant problem.

In the Ice Tempco car, operation of all of the fans was required to adequately disperse the fumigant. Again, ice meltage is a factor in the amount of gas that must be applied.

In mechanically refrigerated cars, the fumigant must be introduced in the space above the load at the doorway or in the "B" end opposite the blower, with the fans operating to obtain satisfactory dispersion of the gas within the load. The doors had to be opened to remove gas from the cars.

These results showed that proper air circulation is essential for satisfactory fumigation of grapes in cars without damaging the fruit.